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- PRACTICAL REFERENCE - RADIATION STANDARDS IN CANADA

Atomic Energy Control Board
Ottawa, Canada

Technical Report

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PRACTICAL REFERENCE
RADIATION STANDARDS IN CANADA

ABSTRACT

In developing a policy that will require licensees to calibrate their radiation dose measuring devices and trace such calibrations to approved reference standards, the AECB has consulted recognized experts. This document presents the experts' reports and recommendations which will be considered in finalizing the policy.

RÉSUMÉ

Dans le but d'élaborer une politique, laquelle demanderait aux détenteurs de permis de calibrer leurs appareils servant à la mesure de doses d'irradiation en suivant les standards de référence approuvés, la CCEA a eu recours à l'avis d'experts reconnus.

Ce document présente les rapports des experts, ainsi que les recommandations qui seront considérées lors de l'élaboration finale de la politique.

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INTRODUCTION

The Atomic Energy Control Board (AECB) is presently considering the implementation of a policy which will require all those licensees who make measurements in order to determine the official radiation dose received by individuals to calibrate their measuring devices on a regular basis following procedures approved by AECB, and to show traceability of such calibrations to AECB approved national reference standards. As part of the implementation step, advice was sought from recognized experts in the appropriate fields of radiation dosimetry. The purpose of this document is to present their unabridged reports and recommendations for information and reference. These recommendations will be taken into consideration in finalizing the policy. In the following text, it should be realized that only the external radiation standards can be classed correctly as primary standards, while the radon and thoron daughter products and *in vivo* standards are really derived reference standards; hence, the expression "reference standards" has been used deliberately.

Until the mid 1970's the Radiation Protection Bureau (RPB) of the Department of National Health and Welfare (NHW) provided most personal dosimetry services to AECB licensees. In 1975, the AECB approved a request from Ontario Hydro to operate its own thermoluminescence dosimetry service, a practice which was considered to allow for more timely corrective action to be taken, as necessary, as a result of dose assignments. Periodic calibrations referenced to National Research Council (NRC) standards formed part of the proposed service. Within the last two years, other major licensees have sought

approval to operate their own dosimetry services. In the absence of a comprehensive AECB policy on the matter of calibrations, licensees have sought their own solutions to the problem of calibrating their equipment. In reviewing the present situation, it is apparent that there is not only a confusing inconsistency in the manner in which calibrations are carried out, but in some cases, suitable practical reference standards do not exist. Consequently, the AECB has developed a policy with regard to the calibration of measuring devices that are used in the determination of dose to individuals.

As already noted, suitable physical standards do not exist in some cases so that a co-operative interdepartmental approach to the development of the necessary standards was adopted with the participation of NRC, NHW, and Energy, Mines, and Resources (EMR). Under the direction of a Co-ordinating Committee made up of representatives from the participating Departments, Working Groups of recognized experts drawn from government agencies, major licensees, and the universities were set up in the Summer of 1982 to provide technical advice regarding the need for, type, and application of reference standards in the fields of external radiation, bioassay, and radon and thoron daughter products.
The reports of the three Working Groups follow this introduction and include their recommendations. The AECB's position is based on these recommendations and can be broadly summarized as follows:

1. External radiation reference standards: at the present time, nuclear power licensees, along with Atomic Energy of Canada Limited, and the Radiation Protection Bureau make use of the gamma ray and neutron radiation standards developed by the National Research Council, and the AECB intends that this practice should continue.

2. Bioassay reference standards: those licensees doing in vitro analysis should continue to make use of standards and solutions supplied by national standards laboratories or by suppliers who have calibrations traceable to these laboratories. These standards are acceptable and it would be difficult to justify the cost of establishing similar facilities in Canada. However, for in vivo measurements, thyroid, thorax, and whole body phantoms should be developed to enable intercomparisons to be made. The Radiation Protection Bureau of the Department of National Health and Welfare has the experience and expertise required to establish, maintain and administer these intercomparison programs.

3. Radon and thoron daughter products reference standards: uranium mining and milling licensees are already involved in informal calibration programs for radon and thoron daughter products, so that the provision of nationally approved standards will ensure that measurements are consistent throughout the industry. To this end, a calibration chamber with appropriate instrumentation should be designed and built which is capable of reproducing easily two standard reference atmospheres of radon daughter products and thoron daughter products. The Elliot Lake Laboratory of the Canada Centre for Mineral and Energy Technology, EMR, has the experience and expertise required to establish, maintain and administer this calibration facility and could incorporate it into the new laboratory planned for 1985/86.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the valuable contributions made by the chairmen and members of each of the Working Groups (their names are given on page 4, immediately before the reports), and the co-operation of the representatives of the participating government departments who served on the Co-ordinating Committee (Dr. P.A. Redhead, NRC; Dr. P.J. Waight, NHW; Mr. T.S. Cochrane, EMR).

TECHNICAL WORKING GROUPS ON THE DEVELOPMENT OF PRACTICAL REFERENCE RADIATION STANDARDS

External Radiation Working Group

Chairman:	Mr. A.R. Jones	Atomic Energy of Canada Limited
Secretary:	Mr. R.E. Utting	Atomic Energy Control Board
Members:	Mr. D. Agnew	Ontario Hydro
	Mr. R. Bradley	Health and Welfare Canada
	Dr. W.G. Cross	Atomic Energy Control Board
	Dr. M. Cohen	McGill University Royal Victoria Hospital
	Dr. W.H. Henry	National Research Council
	Mr. T. Meadley	Amok Limited
	Dr. D.W.O. Rogers	National Research Council

Bioassay and In-Vivo Monitoring Working Group

Chairman:	Mr. C.T. Pomroy	Health and Welfare Canada
Secretary:	Dr. M. Measures	Atomic Energy Control Board
Members:	Mr. M. Deschamps	Université de Montréal
	Dr. D. Gorman	Ontario Hydro
	Dr. J. Johnson	Atomic Energy of Canada Limited
	Mr. W. Neill	Eldorado Resources Limited
	Dr. J. Paciga	New Brunswick Electric Power Commission
	Dr. J. Tai-Pow	Ontario Ministry of Labour
	Dr. R.A. Washington	Atomic Energy Control Board

Airborne Contaminants Working Group

Chairman:	Dr. J. Bigu	Canada Centre for Mineral & Energy Technology
Secretary:	Mr. F.J. Horvath	Atomic Energy Control Board
Members:	Mr. J.L. Chakravatti	Denison Mines Limited
	Dr. P. Duport	Canadian Institute for Radiation Safety
	Mr. J. Viljoen	Atomic Energy Control Board
	Dr. R.A. Washington	Atomic Energy Control Board

WORKING GROUP FOR DEVELOPMENT OF PRACTICAL CALIBRATION STANDARDS FOR EXTERNAL RADIATION

Report to AECB November 1982

OUTLINE OF RECOMMENDATIONS

1. Introduction and General Considerations

2. General Recommendations

3. Recommendations Concerning Personnel Dosimetry

3a. Photons

3b. β-Particles

3c. Neutrons

4. Recommendations Concerning Radiation Protection Measurements

5. Resources Required

6. References

RECOMMENDATIONS TO THE ATOMIC ENERGY CONTROL BOARD ON REFERENCE STANDARDS FOR EXTERNAL RADIATION

1. Introduction and General Considerations

This report is concerned with the standardization of measurements of external ionizing radiations for purposes of radiation protection. Broadly speaking, such measurements are made with two objectives: firstly, in order to assign a radiation dose*, received over a known period of time or during a known procedure, to a given individual. The dose so assigned may refer to the whole body of the individual or to a specified part or region of the body. Secondly, measurements are made either of dose or of dose rate, or a related quantity such as exposure rate or count rate, in various locations in the vicinity of radiation sources or around any facility that may give rise to a radiation hazard. The purpose of these measurements is the assessment of the degree of hazard at the location or area concerned, so that it can be reduced or avoided. This category includes measurements of both radiation fields and of surface radioactivity.

In practice it may not always be possible to draw a sharp distinction between the methods employed in the two kinds of measurement since the techniques overlap to some extent. Nevertheless, the purpose of the measurement is usually quite clear: on the one hand, to evaluate directly a dose already received by an individual; on the other, to evaluate the degree of hazard and hence to estimate indirectly the dose which may be received in the future by persons living or working in particular locations or carrying out duties of a specified nature. Measurements of the second type may also be used to assign a dose that has already been received by an individual in circumstances where no direct measurement of dose is available.

In one important sense the purpose of all measurements in the field of radiation protection is identical: to facilitate the reduction of the radiation exposure of individuals and populations to levels "as low as reasonably achievable...." (ALARA principle). Nevertheless the difference between a direct measurement of the dose received by an individual, and an indirect assessment, as stated above, is significant because statements of dose made by the two methods are very different in terms of accuracy and reliability. This, in turn, influences the desirability and practicality of referring the measurement to a national standard.

Reference to a national standardizing laboratory--the NRC in Canada--refers to the situation in which a measurement is made by a device which has been directly calibrated against a national primary standard. This situation does occur in some areas, such as radiation therapy, but rarely if ever in radiation protection. Thus the reading of a personnel dosimeter, such as a TLD badge, which has been issued, and read out, by one of the agencies for this type of measurement, is linked to the primary standard of dose by a process which involves at least one (and often several) intermediate steps. If these intermediate steps are clearly defined and documented, the field measurement is said to be traceable to the primary standard.

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*The word "dose" is assigned the meaning of "dose equivalent" or "absorbed dose" according to the context.

At a meeting on "Traceability of Ionizing Radiation Measurements", held at the National Bureau of Standards in May, 1980, a number of alternative definitions of "traceability" were put forward. The following definition is a composite of those suggested at the meeting:

> "Traceability is the concept of establishing a valid calibration of a measurement or measuring instrument by means of a step-by-step comparison, and related documentation, with progressively better standards up to an accepted national standard".

Particular attention is drawn to the phrase "and related documentation" since the provision of adequate documentation at each stage is essential to the traceability concept.

Each link in a chain from the NRCC to a field measurement, such as that provided by a personnel dosimeter, contributes its own measure of uncertainty. The overall uncertainty is obtained by summing the individual uncertainties, usually in quadrature although there may be circumstances in which arithmetic summation is more appropriate. If, as is often the case, the uncertainty in one step is much larger than those in the other steps, then this step dominates the whole series and a major effort may be desirable to reduce this particular uncertainty. On the other hand, if the uncertainty in a given step is small relative to the others, then any effort spent in reducing this uncertainty still further is largely wasted since the overall effect is negligible.

For a given chain of measurements, the acceptable uncertainty in any step depends on the contribution of this step to the overall uncertainty, together with the acceptable magnitude of the overall uncertainty. Here, however, there may be a difficulty: the acceptable overall uncertainty may not coincide with what is reasonably achievable. The Committee examined this point with specific reference to the overall uncertainty in the chain leading to a reading of a TL personnel dosimeter badge and the assignment of a dose to the individual who has worn the badge.

It will be noted that the final link in the chain is not the direct measurement of the dosimeter but the dose assigned to the individual on the basis of that measurement. It is usually assumed that, unless otherwise shown, these values are identical: the individual receives whatever dose the badge indicates. Indeed, no other assumption is possible. If the radiation giving rise to the dose is penetrating and multidirectional and the individual moves around a great deal, then the assumption of a uniform body dose, equal to the badge dose, is justified. If, however, the radiation is essentially unidirectional and the person largely maintains a single orientation, then the badge reading may be quite unrepresentative of the body dose. This is a problem that could be investigated fairly readily by arranging for selected radiation workers to wear a number of badges in various positions on the body. Indeed, it is likely that the greatest single

measure to improve the accuracy of personnel dosimetry would be to oblige selected workers--those routinely subjected to relatively large doses--to wear two badges. There is the further problem, whose solution is administrative rather than scientific, of badges that are mistreated, unworn, or left in the vicinity of radiation sources or strong sources of heat.

The Committee believes, on the basis of the available evidence,[1,2] that the body dose actually received by a radiation worker lies between -50% and +20% of the dose measured by a personnel dosimeter. This means that, if 1.0 rem is assigned on the basis of the dosimeter reading, then the actual body dose is likely to be between 0.5 rem and 1.2 rem. Thus the negative uncertainty is greater than the positive and the assigned dose is more likely to be an overestimate than an underestimate, in conformity with the usual conservative principles of radiation protection. Further, these uncertainties apply to: (a) a "perfect" dosimeter--one which records the physical dose with zero uncertainty; (b) an annual or quarterly exposure in which the contribution from sources behind the exposed worker is not dominant.

The estimated uncertainty in the final link of the personnel dosimetry chain, as discussed above, leads the Committee to consider that the overall uncertainty in the chain up to the penultimate step, i.e., the overall uncertainty in the measurement of dose by a personnel dosimeter, should not exceed ±20%. Thus the overall uncertainty in the assignment of dose for a period of time (e.g., 1 year), on the basis of a series of dosimeter readings, should not be greater than

$$-\sqrt{20^2 + 50^2} = -54\%, \quad +\sqrt{20^2 + 20^2} = +28\%.$$

The Committee believes that these uncertainties are scientifically acceptable, in the light of the inherent difficulties of completing the final link in the chain, that between dose measurement and dose assignment. The Committee is aware, however, of the problems that may be encountered in some quarters in understanding and accepting the implications of these figures.

The readings of personnel dosimeters serve a number of purposes. For the individual radiation worker, they provide an assurance of his safety. The values are entered on his record and may even be used for legal or compensation purposes. For the employer, the records as a whole provide valuable evidence as to the efficacy of the measures taken to ensure radiation safety and proof that legal dose limits are respected. For the employees as a group, the dose records play a vital role in engendering confidence in the system of radiation safety operating in the workplace.

The question of confidence is crucial, since no enterprise utilizing radiation sources can function smoothly if the validity of the dose records of the workforce is seriously questioned. It is important, therefore, that the readings of personnel dosimeters be generally accepted as valid indicators of the doses actually received by the individuals concerned and that the uncertainties associated with these readings be perceived as the lowest achievable by the "state of the art". For this reason the Committee believes that a demonstrable and fully documented traceability chain is essential. Such a chain already exists in the case of personnel dosimeters but has not so far been adequately documented.

The recommended accuracy of ±20% in the overall chain up to the reading of a personnel dosimeter is already achieved by all of the organizations operating personnel dosimetry services in Canada. The estimated uncertainties in the final dosimeter reading range from ±7% to ±16%, to the level of two standard deviations. The uncertainty in the first link in the chain, i.e., the measurement of exposure at the NRCC, is in the range 2-4%, which is small compared with the overall uncertainty in the chain. Further details are given in Section 3 of this report, with specific reference to personnel dosimeters used for the measurement of photons, β-particles and neutrons.

Finally, the Committee considered the question of traceability of devices used for the assessment of radiation hazards. The link between the reading of an area monitor, or the count rate of a surface monitor, and the dose likely to be received by an individual radiation worker, is extremely weak. These readings are essentially of a relative rather than an absolute nature. In order to establish a link with an individual dose one has to make assumptions, which may be "conservative" or "realistic", as to the time which the individual will spend at or near the location where the exposure or count rate has been monitored, the nature of the procedures to be carried out, the type and energy of the radiation to which he will be exposed, and so on. Only exceptionally can an accurate, realistic "scenario" be constructed which leads to a valid assignment of dose; otherwise the readings of area and surface monitors are valuable only as guides to radiation safety. For this reason, as will be further elaborated in Section 4, the Committee does not recommend mandatory traceability for these devices, although voluntary traceability (especially for newly manufactured devices), together with the regular use of check sources to monitor performance, should be encouraged.

2. General Recommendations

We recommend that organizations authorized to assign doses for record purposes document the means by which measurements of body and skin doses* are traced to National Research Council standards.

*The word "dose" is assigned the meaning of "dose equivalent" or "absorbed dose" according to the context.

Although the methods are not all the same, all are capable of providing measurements consistent with NRCC standards within uncertainties acceptable for personnel dosimetry.

We recommend that users of instruments for the assessment of radiation hazards (e.g., β- and γ-dose rate meters and surface activity meters) not be required to trace their calibration to an NRCC standard. However, such users should be required to use check-sources to monitor the constancy of instrument performance. Further, in the case of γ-dose rate meters, it is recommended that the NRCC continue to offer calibration services to instrument users and manufacturers requiring such services.

3. Recommendations Concerning Personnel Dosimetry

3a. Photons

At each organization performing personnel dosimetry there is a ^{60}Co or ^{137}Cs source used in the calibration of the personnel dosimetry systems. At a point or at a number of points in the photon field of the source there are measurements made traceable to the ^{60}Co exposure standard at NRCC.

At the measurement points referred to, dosimeters are exposed for known periods and, with their use, the dose to the wearers of similar dosimeters is estimated.

We recommend that each organization continues the methods now being used to relate its photon dosimetry to the NRCC Standard. However, each organization should document its traceability to the NRCC Standard if it has not already done so.

For the present, we recommend the continued use of exposure, and the unit roentgen, for the reference quantity. When the ICRU gives guidance on this subject, exposure should be replaced by the appropriate form of kerma with its unit, the gray.

For the purpose of personnel dosimetry an uncertainty of ±5% in the exposure measurement made at NRCC is adequate.

3b. Beta Radiation

Measurements of skin doses from external beta rays present special difficulties that make the accuracy and reliability of the results

significantly poorer than those of gamma-ray measurements. This poorer performance arises primarily from the strong attenuation and scattering of beta rays. In particular, there is often considerable attenuation over the thickness of the TL dosimeter. Whereas the objective is to measure the skin dose at a depth of 7 mg/cm^2*, most Canadian dosimetry systems use skin dosimeters having thicknesses of 67 or 100 mg/cm^2 (and a cover of 7 mg/cm^2) and read the average dose over this thickness. The difference between the measured dose and that at 7 mg/cm^2 varies with beta-ray energy. For example, with thin, uncovered beta sources 30 cm from the skin, a dosimeter 100 mg/cm^2 thick (as presently calibrated) would read about 69% of the skin dose for a $^{90}Sr/^{90}Y$ source, and 37% for an ^{131}I source. These errors will also depend on the thickness of the source and of any covering over it.

In addition, the attenuation and scattering of beta rays by air and by the body make beta doses less nearly uniform than gamma doses and lead to larger differences between the average dose to the skin and the dose read on a single badge.

At present, personal skin dosimeters are calibrated with a known exposure of ^{60}Co or ^{137}Cs gamma rays. They are usually covered by enough low-Z material to ensure secondary-electron equilibrium. With this procedure, they read the average dose over their volume. For high-energy, normally-incident beta particles, their reading gives a reasonable approximation to the skin dose but the error increases markedly as the beta-ray energy decreases. Skin dosimeters can also have considerable errors resulting from non-uniform angular response to beta rays.

In general, these errors are not of great practical importance because (a) beta rays often contribute only a minor part of skin doses, (b) the ICRP limits for skin doses are 10 times higher than for whole-body doses and, (c) in the nuclear power industry, at least, beta doses often arise predominantly from relatively high energy beta emitters. Nevertheless, circumstances may occur where beta-ray doses are the limiting factor and where the uncertainties of assigned skin dose equivalents are undesirably high.

To improve this situation requires the development of better skin dosimeters and a better understanding of the limitations of existing dosimeters. Study of the response of dosimeters in well-calibrated beta-ray fields of various known energy spectra will contribute to this objective. (Sources of 3 beta emitters, calibrated by the national standards laboratory of the Federal Republic of Germany, are becoming widely-used). However, the routine calibration of dosimeters with beta rays of a particular maximum energy would not make any significant improvement to the accuracy or reliability achieved at present. The present system of calibration with gamma rays can ensure uniformity with time and among different dosimetry

*While this depth is presently recommended by the ICRP for measurement of skin dose, there is evidence that the dose at a greater depth would give a closer indication of the biological hazard.

services.

Uncertainties in the gamma-ray exposures now used for calibration would contribute a negligible amount to the overall uncertainties of assigned skin doses, whether or not these exposures were calibrated against national standards. In current practice these ^{60}Co and ^{137}Cs exposures are referenced to NRCC measurements. This practice appears to be satisfactory and we recommend that it be continued at present.

3c. Neutrons

Because the state of neutron personnel dosimetry is still unsatisfactory we recommend that at the present time neutron dosimetry systems not be required to trace their calibration to an NRCC Standard.

There is currently considerable research and development going on in this area and it is possible that more reliable personnel monitoring systems will be in place in the future. At that time, and if the perceived risks from neutron hazards increase, it is possible that some sort of traceability requirements would be worthwhile. If, as appears likely, the new system is some combination of albedo and track-etch dosimeters the calibration services currently available at the NRCC would appear to be adequate and we recommend that they continue to be provided.

In the meantime the committee notes that the NRCC offers a variety of neutron calibration services which can be used to calibrate neutron dosimeters and remmeters or to develop new personnel dosimeters. The services include: the calibration of Am-Be sources in terms of neutron fluence; irradiation of small instruments in a thermal neutron cavity; calibration of remmeters using the known fluence rate and spectrum from an Am-Be source and a calculated conversion factor to dose equivalent rate; and provision of fluence calibrated monoenergetic neutron beams in the 20→1000 keV region. The provision of calibrated monoenergetic neutron beams is based on an accelerator and hence both more expensive and less accurate (±20%) than the other modalities.

4. Recommendations Concerning Radiation Hazard Measurements

The recommendations contained in this section deal explicitly with all instrumentation not used to assign doses to individuals. In this category of instrumentation we include all devices such as hand-held and area survey meters, surface contamination measuring devices, as well as all types of direct reading personal dosimeters. The measurements made with these instruments are primarily performed for assessing hazards. Most of these instruments are rate-meters (count or dose) but some integrate the measured quantity. In either case their readings are essentially relative in nature.

We recommend for this category of instrumentation that traceability requirements not be introduced.

We do recommend that constancy checks, using check-sources, be required to be carried out. Such checks should be performed by the users at reasonable frequencies. These tests will be used to establish any changes in performance relative to the readings determined by the initial testing of new equipment by the user. Calibration and performance data supplied by the manufacturer will establish the expected values for these tests.

Canadian manufacturers of radiation hazard measuring instruments should be made aware of and encouraged to use the resources of the NRCC for both calibration and type testing. Further, any claims of traceability made by manufacturers should be substantiated by adequate documentation.

Finally it is also the committee's opinion that those organizations who wish to have calibrations performed by the NRCC be so encouraged to do so. The NRCC has indicated its willingness to continue providing these services.

References

1 Proposed Calibration Factors for Various Dosimeters at Different Energies. A.R. Jones. Health Physics 12, p.665 (1966).

2 External Gamma Dosimetry in the Light of ICRP-26. A.R. Jones and R. Marsolais. Trans. American Nuclear Society 32, 659 (1979).

WORKING GROUP FOR DEVELOPMENT OF PRACTICAL CALIBRATION STANDARDS FOR BIOASSAY AND IN-VIVO MONITORING

Report to AECB November 1982

Working Group for Development of Practical Calibration Standards for Bioassay and In-Vivo Monitoring

Report to AECB November 1982

INTRODUCTION

The Working Group, established on the initiative of the Atomic Energy Control Board, and under the chairmanship of a representative of the Dept. of National Health and Welfare, has prepared the following report and recommendations according to the terms of reference set out the AECB document of June 82.

Before addressing the specific headings in that document, a general description of the present situation will be given.

The monitoring of internal contamination,and the estimation of internal dose, can include considerable variation in accuracy and effectiveness at present. To a large extent the variation is due to the fact that for some radionuclides e.g. tritium oxide in the body, or ^{125}I in the thyroid, measurement of the basic parameters is relatively easy and the conversion of these to dose values is based on well established metabolic models. For many other radionuclides, however the basic measurement is quite difficult to perform with accuracy, and metabolic data are also either not available or questionable. This illustrates the fact that "calibration" of bioassay methods, from which internal doses are derived, is a two part process. The first is the calibration of the basic measurement technique. This will involve an instrument calibration, of, for instance, a liquid scintillation counter, or whole body counter, to ensure that the radioactivity in the sample or subject is being accurately measured. In addition, some bioassay

measurements also require considerable chemical preparation before the counting stage is reached, and in these cases a form of quality control is required to account for chemical preparation and counting errors.

The second part of the process is the conversion of a bioassay measurement to a dose, which involves the choice of an appropriate metabolic model. This aspect will not be addressed in this document. Reference should be made to the series of documents prepared by the Federal-Provincial Working Group on Bioassay and In-Vivo Monitoring Criteria, which include details of metabolic models for specific radionuclides (1,2,3).

This present report also distinguishes between bioassay measurements made for exposure control or other reasons, and those made for dosimetry purposes. Only the latter are included in the AECB terms of reference, and thus only those will be discussed.

TRACEABILITY

A detailed discussion of traceability is given by Eisenhower (4) and the following remarks are based on his paper.

Traceability may be either direct or indirect, the latter being when more than one intermediate step exists between the measurement and the national standard. The major elements of a traceability measurement support system are:

1) measurement standards - national and transfer * standards
2) calibrations of transfer standards by the national laboratory
3) measurements quality assurance programs.

These elements would be provided by:

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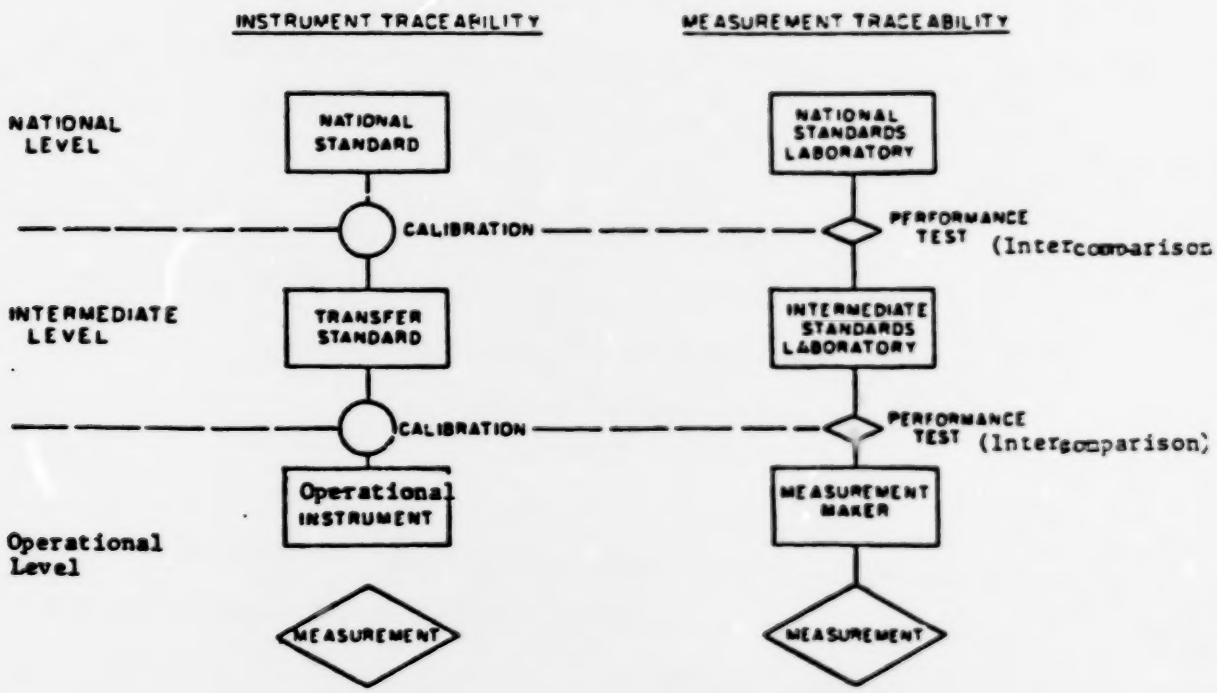
* Transfer standards are included here for completeness of the general discussion. The recommendations of this report, however, are concerned with national standards only.

1. National Standards laboratory which maintains national reference standards and provides related services.
2. Intermediate standards laboratories that use transfer standards as the basis of calibrations and other services provided by them.

An important aspect of the bioassay calibration procedures is the quality assurance program. This should include procedures that enable a laboratory to ensure on a continuing basis that the total measurement uncertainty relative to the national standard is quantified and sufficiently small to meet requirements. Such an intercomparison program should be administered by an AECB designated national laboratory, so as to provide direct measurement traceability. Between performance tests, each laboratory should have in place an internal quality control program, which should include methods that would warn of problems with the measurement procedure. It is important that a distinction is made between instrument traceability and measurement traceability, and the following diagram from Eisenhowers' paper shows the difference:



DEFINITIONS

For the purpose of this report, the following terms are defined; in some cases with a more restricted meaning than in the preceding paragraph.

Calibration:

The process by which a laboratory establishes the quantitative response of its own measurement system.

Instrument traceability:

The ability to show that a particular instrument or measurement system has been calibrated, directly or indirectly,against an appropriate national standard. This is the responsibility of the individual laboratory.

Intercomparison:

The process by which a laboratory demonstrates the extent of the agreement of its calibrated response with that of a national laboratory, and verifies its measurement capability.

Measurement traceability:

The ability to show that the end result or measurement by a measurement system, which may be either a detection system, or an analytical procedure, is consistent with an appropriate national standard.

It is the opinion of the Working Group that calibration and instrument traceability, as defined above, are the responsibilities of individual laboratories. Intercomparison and measurement traceability however, are the mechanisms by which a laboratory demonstrates its capabilities to national authorities.

Calibration Standards:

Calibration standards should be traceable to a laboratory with an established and accepted reputation for accuracy and reliability. In Canada

most laboratories use standards, e.g. certified calibrated solutions, traceable to the National Bureau of Standards in Washington or, less frequently, the National Physical Laboratory in England or the CEA in France. The working group sees no reason to change this arrangement.

INTERCOMPARISON STANDARDS

These consist of phantoms for in-vivo measurement systems and samples for intercomparison programs for analytical procedures, that are maintained and administered by a national laboratory.

SPECIFICATIONS AND SCOPE

The following types of measurement are used (or could be used) for dosimetric purposes.

i) In-vivo measurements:

a) Radioiodine in the thyroid involving mainly ^{125}I and ^{131}I, but other iodine isotopes could be involved.

b) Thorax measurements for lung burdens of uranium (natural, enriched and depleted) natural Thorium, and ^{241}Am (for ^{239}Pu).

c) Other in vivo measurements for fission products and other medium to high energy gamma emitters.

ii) In vitro measurements:

a) ^{3}H in urine

b) Other β emitters in urine such as:

^{14}C, ^{32}P, ^{33}P, ^{35}S, ^{45}Ca, ^{63}Ni, ^{90}Sr, ^{90}Y, ^{140}Ba, ^{147}Pm, ^{210}Pb.

c) α - emitters, such as uranium, plutonium, in urine or feces.

QUANTITY TO BE MEASURED

These measurements are expressed in terms of activity or activity concentration, and not in terms of dose or exposure. For in vivo measurements

the unit is the Bq, and for in vitro measurements the unit is Bq L^{-1} or Bq kg^{-1}.

Because of the use of a model, with its inherent approximations, to derive dose estimates from bioassay measurements, it should be emphasized that the error in dose estimate will be greater, sometimes substantially so, than the error in the bioassay measurement.

FORM OF STANDARDS

i) In-vivo reference phantoms

a) Thyroid - a realistic model neck, made of tissue-equivalent material for energies from 20KeV to 2MeV, and containing a removable, realistically modelled thyroid gland that can be filled with radioactive solution.

b) Thorax - a realistic model torso, of dimensions appropriate to a North American adult male, made of tissue-equivalent material for energies from 15KeV to 3MeV, and containing removable, realistically modelled lungs and pulmonary lymph nodes, impregnated with radioactivity.

c) Other in-vivo phantoms - adult-sized phantoms of ellipsoid or cylindrical sections, made of polyethylene, that can be filled with solutions of radionuclides. A modified version of this type of phantom will be required for use with chair-type in vivo measurement systems.

Full descriptions of all these reference phantoms will be provided by the Radiation Protection Bureau, and should be subject to review by the Federal Provincial Working Group on Bioassay and In Vivo Monitoring Criteria.

ii) Samples for intercomparison programs for analytical procedures

These programs involve the preparation, from a traceable standard, of a series of samples of different concentrations in the range commonly encountered in biological samples measured by participating laboratories.

Descriptions of these programs will be available from Radiation Protection Bureau and should be subject to review by the Federal Provincial Working Group on Bioassay and In Vivo Monitoring Criteria.

MODUS OPERANDI

i) In Vivo:

The various reference phantoms will be maintained by Radiation Protection Bureau and circulated to participating laboratories, usually accompanied by R.P.B. staff.

All in vivo measurement systems used for dosimetric estimations must be compared to the reference phantoms when the dosimetry system is set up and again if any changes are made to the system that could affect its calibration.

ii) In Vitro Analytical procedures:

The intercomparison program samples will be prepared and distributed by Radiation Protection Bureau in general on a 6 month frequency. The concentration of radioactivity in the samples will be unknown to the participating laboratory, although they will of course be aware that the samples are for intercomparison purposes. Results will be sent to Radiation Protection Bureau.

Accuracy requirements and "pass or fail" criteria for both in vivo and in vitro intercomparisons have yet to be established. This should be done in consultation with the Federal Provincial Working Group on Bioassay and In Vivo Monitoring Criteria.

RECOMMENDATIONS

1. The Radiation Protection Bureau, Health and Welfare, should be responsible for the establishment, maintenance and administration of intercomparison programs for in vivo measurements and in vitro analytical procedures. This will involve the purchase and construction of appropriate reference phantoms, and the preparation of spiked samples of biological material such as urine; the circulation or distribution of the phantoms or samples; and the analysis of the results obtained by participating laboratories.
2. Intercomparisons for in vivo measurements should be done when a laboratory establishes an in vivo measurement system, and thereafter if any changes are made to the system that could affect its calibration. The reference phantoms used for these intercomparisons should generally be accompanied by RPB personnel.
3. Intercomparisons for in vitro analytical procedures should be done, in general, on a six month frequency. A series of spiked samples of appropriate biological material should be circulated to participating laboratories, with instructions to analyse them and send the results within a set time period to RPB.
4. Full descriptions, including traceability data, of these intercomparison programs should be provided by R.P.B. to participating laboratories.
5. Specifications for reference phantoms, accuracy requirements, and "pass or fail" criteria should be set in consultation with the Federal-Provincial Working Group on Bioassay and In Vivo Monitoring Criteria.

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ON THE ESTABLISHMENT OF PRACTICAL REFERENCE STANDARDS FOR CALIBRATION PURPOSES IN CANADA FOR RADON, THORON AND THEIR SHORT-LIVED DECAY PRODUCTS, AND OTHER AIRBORNE RADIOISOTOPES

A report submitted to the AECB
by
The Working Group on Airborne Contaminants

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FOREWORD

There is an ever increasing awareness of the need to identify and control airborne radioactive contaminants; to define experimental procedures, methods and techniques to determine these contaminants; and to establish adequate facilities to test and calibrate instrumentation used to determine radiation levels associated with airborne contaminants.

The Atomic Energy Control Board (AECB) has recently approved in principle a policy which will require all AECB licensees to calibrate on a regular basis the devices and systems used in estimating radiation levels, radiation dose and for measuring radiation dose rate, and to show traceability of such calibrations to AECB approved national standards.

While suitable standards exist in Canada to meet the above requirements for some licensed operations, e.g., those which make use of γ-radiation and neutrons and for which exposure standards have been developed by the National Research Council (NRC), there are other operations for which no standards exist, in particular in the area of airborne contaminants which include the uranium mining, milling, processing, refining and fuel fabrication industries, nuclear reactor installations, and some uses of radioisotopes. Other areas for which no suitable standard exists include external radiation and bioassay.

In the absence of calibrations that are traceable to approved practical reference standards, it is not possible to make reliable comparisons of radiation data generated by AECB licensees. Accordingly, the AECB, Health and Welfare Canada, Energy, Mines and Resources Canada and the NRC have agreed to establish three working groups to address the technical questions arising in the development of the required reference standards for (i) external radiation, (ii) airborne contaminants, and (iii) bioassay.

The material that follows contains the findings and recommendations of the working group on radioactive airborne contaminants, and as such includes the uranium mining, milling, refining and fuel fabrication industries as well as nuclear reactor installations, and some uses of radioisotopes.

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BACKGROUND

Monitoring of radiation levels is not only relevant in engineering applications but most importantly for health and radiation protection purposes. Monitoring is carried out with specialized instrumentation and the accuracy of monitoring greatly depends upon the reliability of the methodology and instrumentation used. The precision of the methodology and the quality performance of the instrument can only be determined by adequate calibration procedures under well defined and reproducible conditions.

Radiation instrumentation has been developed for environmental and personnel monitoring purposes using both passive and active operating principles. In general terms, radiation instrumentation can be divided into two main kinds, namely: grab-samplers and continuous monitors. The latter can be further subdivided into discrete/continuous monitors and continuous monitors operating on time-integrating principles. All of the above kinds of instrumentation are commonly used for environmental monitoring whereas only instrumentation based on time-integrating principles is employed for personnel monitoring, i.e., personal dosimeters.

Different radiation instruments have been designed that make use of different methods for determining radiation levels. Broadly speaking, these instruments can be divided into three main categories:

1. Instruments which enable in principle the use of almost any available method but which involve a great deal of manual operation;
2. Fully automatic, microprocessor-controlled, instruments which permit the use of several pre-programmed methods on command;
3. Fully programmable, microprocessor-controlled, instruments which permit the use of any method, in addition to pre-programmed methods stored permanently in the computer memory of the instrument.

There are a variety of experimental methods presently available for determining the airborne concentration of radon, thoron and their decay products and other airborne radioisotopes, the choice of method depending upon the particular application.

Because of the great variety of radiation instrumentation commercially available and presently in use, and because of the number of different methods employed by the instruments for determining radiation levels, there is a clear need for:

(a) Evaluating the long-term performance and reliability of the instrument;

(b) Studying the response of the instrument under a variety of environmental conditions; and

(c) Calibrating the instrument under well defined and reproducible conditions by means of reference radioactive atmospheres of known characteristics.

Instrumentation for determining radon, thoron and their decay products, and other airborne radioisotopes of interest consist basically of a sampling system and a counting system. In some instruments these two systems are mechanically integrated whereas in other instruments the two systems are physically separated.

The sampling system consists of a sampling pump, a flowmeter, and a filter/filter holder unit. In the case of radioactive gases, the filter is used to remove their decay products before entering the detector. However, in the case of decay products, the filter is employed to collect these products for measurement. (Note: instruments operating on passive principles do not employ a sampling pump.)

The counting system consists of a suitable radiation detector and associated electronic circuitry for signal processing and counting. In some cases all mechanical and electronic operations are microprocessor-controlled. There is a great variety of mechanical and electronic configurations commer-

cially available, their description, however, is beyond the scope of this document.

Regardless of the method and analytical procedure used in the determination of the airborne radioisotopes of interest, the sampling flow rate and the detector counting efficiency must be known accurately. In addition, the characteristics of the sampling filter are of interest as they affect the absorption of radiation, e.g., self-absorption, and hence corrections need to be applied in the calculations if reliable results are to be obtained.

From the above discussion one may surmise that the following items should be considered in order to determine the performance and reliability of a radiation instrument for laboratory or field use:

1. Calibration of the sampling pump/flowmeter unit;
2. Determination of the counting efficiency of the detector and associated electronic circuitry; and
3. Study of the characteristics of the sampling filter to be used.

Items 1 and 2 although important are not the only ones. Firstly, filter holders exhibit variable degrees of decay-products plate-out which depend on the mechanical configuration of the holder (e.g., shape, size, material used) and sampling flow rate. Secondly, the size and shape of the instrument, as a whole, greatly affects the air flow pattern around it, it influences the sampling characteristics of the sampling head of the instrument, and it increases plate-out of radioisotopes on the walls, e.g., surfaces of the instrument, which in turn affect the collection of these products in the sampling filter. Thirdly, the mechanical configuration and position of the sampling head relative to the rest of the instrument plays a role in plate-out, air flow patterns and other important considerations.

As the size, shape and sampling system configuration varies considerably

from instrument to instrument one may conclude that it is not sufficient to calibrate the sampling system and determine the detector counting efficiency, as indicated above, but that it is of utmost importance to determine the overall 'performance' of the instrument by calibrating it in a reference radioactive atmosphere of known characteristics approaching as closely as possible those of field conditions. The characteristics of this reference atmosphere should be determined by a reference method and reference instrumentation.

The remainder of this report deals with the technical aspects and considerations of the above topics and makes recommendations as to the establishment of practical reference standards for calibration purposes of radiation instrumentation for determining radon, thoron, and their short-lived decay products (also known as daughter products), and other relevant airborne radioisotopes. For simplicity, the following discussion has been divided into two main sections. The first section deals with radon, thoron and their short-lived decay products (see items A through H). The second section deals with other airborne radioisotopes of interest including uranium, radium and thorium, i.e., long-lived radioactive dust, beta (β) radiation, and other topics (see item I through K). A list of topics dealt with follows:

A. Reference radon, thoron and their decay products atmospheres for the calibration of radiation instrumentation;

B. Design of a radon/radon daughter and thoron/thoron daughter test facility for the calibration of radiation instrumentation;

C. Reference methods for determining radon, thoron and their daughter products in a reference atmosphere;

D. Reference radiation instrumentation;

E. Operational procedures for the calibration of radiation instruments in the test facility;

F. Primary and secondary standard sources for the determination of α-counting efficiency;

G. Primary and secondary standard sources for radon and thoron gases;

H. Estimated cost, manpower requirements, maintenance and completion date of test facility;

I. Long-lived radioactive dust, uranium and thorium standard sources;

J. Beta radiation;

K. Other topics; and

L. Summary of recommendations.

Finally, it should be emphasized that calibration or reference standards for radioactive airborne contaminants are only required in the context of this discussion for those situations in which the results of air sampling are used to demonstrate compliance to AECB regulatory exposure limits. Calibration or reference standards although useful are not required for situations in which air monitoring is performed only for planning and control purposes.

A. REFERENCE RADON, THORON AND THEIR DECAY PRODUCTS ATMOSPHERES FOR THE CALIBRATION OF RADIATION INSTRUMENTATION

Radiation instruments whose use is intended for routine environmental and personnel monitoring need to be periodically calibrated against radioactive atmospheres of known characteristics. A radon/radon daughter atmosphere may be defined or characterized in terms of the following variables:

1. Radon gas concentration;
2. Radon daughter concentration;
3. Radon daughter disequilibrium ratio;
4. Attached and unattached daughter fractions;
5. Aerosol concentration and size distribution;
6. Relative humidity or air moisture content;

7. Temperature.

However, because some of the above variables can to some extent change or be changed independently from one another, and because other variables are interdependent, actual radon/radon daughter atmospheres encountered under field conditions may vary considerably with time and location. For these and other reasons, it is sufficient for practical purposes to produce a limited number of reference standard atmospheres of known, reproducible, characteristics representative of actual field conditions. The same arguments indicated above for radon/radon daughter atmospheres apply equally well to thoron/thoron daughter atmospheres, and mixtures of radon and thoron and their decay products.

Reproducibility of reference atmospheres of precisely defined characteristics including decay product concentration, aerosol concentration and size distribution is, however, difficult unless reasonable allowable ranges for the different variables of interest are tolerated. In addition, there is a practical need to calibrate and test radiation instruments under 'normal' environmental conditions and 'extreme' environmental conditions of, say, relative humidity (or air moisture content), temperature, and aerosol and dust concentration. Hence, it is convenient for practical purposes to define a 'normal' reference atmosphere and an 'extreme' reference atmosphere. This distinction is particularly relevant to investigate the response of instrumentation to plate-out phenomena which arise under low aerosol concentrations.

The following are the recommended characteristics and values for some variables pertaining to the two reference atmospheres discussed above.

'NORMAL' REFERENCE ATMOSPHERE

Working Level (WL):	0.1 to 3.0	(0.3)
Disequilibrium ratio:	~ 1:0.6:0.4	(for radon daughters)
Disequilibrium ratio:	~ [ThC]/[ThB]*=0.5	(for thoron daughters)
Aerosol concentration (N):	$\gtrsim 10^5$ cm^{-3}	
Average Median Aerodynamic Diameter (AMAD):	0.1 to 0.2 μm	(polydispersed)
Relative humidity (R.H.)	50% to 80%	(70%)
Temperature (T):	20 ± 3°C	

'EXTREME' REFERENCE ATMOSPHERE

Working Level (WL):	0.1 to 3.0	(0.3)
Disequilibrium ratio:	~ 1:0.6:0.4	(for radon daughters)
Disequilibrium ratio:	~ [ThC]/[ThB]*=0.5	(for thoron daughters)
Aerosol concentration (N):	$\lesssim 10^3$ cm^{-3}	

* Square brackets stand for concentration.

AMAD:	0.1 to 0.2 μm	
Relative humidity (R.H.):	10% to 50%	(30%)
Temperature (T):	20 ± 3°C	

The basic difference between the above reference atmospheres is in the aerosol concentration and the air moisture content. The values in brackets are suggested as the most representative for calibration purposes.

B. DESIGN OF A RADON/RADON DAUGHTER AND THORON/THORON DAUGHTER TEST FACILITY FOR THE CALIBRATION OF RADIATION INSTRUMENTATION

The Elliot Lake Laboratory (ELL), CANMET, is presently operating two radon/radon daughter and thoron/thoron daughter test facilities, namely a small one of 3000 L volume mainly for research purposes and a large facility of 3.6×10^6 L volume, on an experimental basis, for routine testing and calibration of radiation instruments.

One major conclusion derived from the experience so far gained with these two facilities is that a test facility exclusively dedicated to routine calibration purposes should be practical and easy to operate. Thus, the test facility should be large enough to:

1. permit easy access to it by personnel and instrumentation;
2. enable testing and/or calibration of a relatively large number of instruments at a time, whereby the instruments are to be placed inside the facility to simulate actual field conditions;
3. be easy to maintain, repair and modify internally.

Based on the above criteria, it is recommended that a relatively large test facility be built of dimensions similar to, or perhaps somewhat smaller than, the one indicated above, i.e., 3.6×10^6 L. Furthermore, as the only basic difference between a radon/radon daughter test facility and a thoron/thoron daughter test facility is the radioactive source, it is recommended

that only one test facility should be built with capabilities to generate both radon/radon daughter and thoron/thoron daughter atmospheres or a mixture of both atmospheres. In addition, rather than building a large volume container to contain the reference atmosphere, it is suggested that a specially designed room would be preferable and would reduce cost considerably without significant reduction in performance.

INSTRUMENTATION AND SOURCES REQUIRED TO OPERATE THE TEST FACILITY

The kind of instrumentation and equipment required to operate a test facility of the type under discussion can be divided into three main categories:

1. Control instrumentation. That is, instrumentation used to produce and control the reference atmosphere within the desired range and characteristics of interest;
2. Monitoring instrumentation. This is the instrumentation required to monitor the various variables of interest from which the reference atmosphere is composed;
3. Auxiliary equipment; and
4. Radioactive sources and aerosol sources.

Control Instrumentation

The control instrumentation would include:

(a) Radon and thoron sources (i.e., Ra-226 and Th-228 sources, respectively) of the flow-through type, and their associated filtering, desiccating and pumping systems necessary in order to produce and inject 'clean' radon gas (Rn-222) and/or thoron gas (Rn-220) into the test facility;

(b) Aerosol source(s) and associated apparatus in order to produce the aerosol concentration and size distribution characteristics required. The aerosol source system could consist of a compressed air system, and an aqueous

solution of the aerosol in an atomizer followed by a desiccator column and aerosol neutralizer to remove excess moisture and neutralize the aerosol charge, respectively. Alternative methods of generating aerosols are also considered according to needs, e.g., NiCr filament method.

(c) Air moisture content and air temperature control equipment to regulate the above variables in the test facility. Air conditioning could be realized in a 'buffer' chamber outside the test facility by means of a humidifier/dehumidifier/heater/fan system. Conditioned air of the desired characteristics could be injected directly into the test facility or it could be pre-mixed with the aerosol supply and/or radioactive gas supply prior to injection into the facility;

(d) Air flow control system to regulate the flow of air in the test facility. This would entail an exhaust/pumping system to either exhaust the radioactive gas/daughter products mixture into the atmosphere, or to recirculate the mixture back into the test facility. Air flow control permits regulation of the radioactive gas to daughter products ratio and of the daughter products disequilibrium ratio, two ratios of considerable practical importance; and

(e) Air mixing by small mixing fans inside the test facility to 'homogenize' the reference atmosphere, i.e., to minimize concentration gradients. An ion-generator should also be used inside the test facility to regulate the atmospheric, i.e., air, electrical charge density which greatly affects the plate-out of daughter products on surfaces, e.g., walls.

Monitoring Instrumentation

Monitoring instrumentation includes the following:

(a) Radon and thoron gas continuous and discrete monitoring facilities. This

can be done by means of a scintillation cell, e.g., ZnS(Ag), optically coupled to a photomultiplier tube/scaler system in conjunction with a sampling system consisting of a pump, calibrated flowmeter and filter holder/filter. The reference atmosphere is sampled through the scintillation cell after removing the daughter products by means of the filter. The scaler is microprocessor controlled so that the counting time and interval time between successive counts can be programmed. Experimental data are given in print-out form by means of a thermal printer. Usually, sampling of the reference atmosphere is done in a closed-loop, in-line fashion through adequate sampling ports located in the test facility;

(b) Radon and thoron daughter product continuous and discrete monitoring facilities. This can be attained by means of an α-detector, preferably of the ruggedized Si-barrier or diffused-junction type with associated α-spectroscopy capabilities, i.e., preamplifier/amplifier/multichannel analyzer. A sampling 'head' is used which holds both the detector and a sampling filter face to face. Sampling of the reference atmosphere is done by means of a sampling train consisting of a sampling pump and calibrated flowmeter. Sampling is carried out in a 'closed-loop', in-line fashion. Data print-out and read-out are provided. As with the radon and thoron gas case, the electronic system, including sampling and counting are microprocessor-controlled. (Note: some commercially available radon daughter instruments incorporate all of the above components and capabilities, and can, therefore, be used directly for this type of application.) It is of practical interest to monitor the Working Level by measuring β-activity instead of α-activity. This method is identical to that described above, the only difference being the use of, say, a G-M β-detector

and a scaler for gross β-counting instead of the Si-barrier, or diffused-junction, detector and α-spectroscopy capabilities, respectively.

(c) Aerosol concentration and aerosol size distribution capabilities. This would consist of a condensation nucleus counter (CNC) in conjunction with a particle size selector. Data can be obtained in a discrete fashion by direct instrument read-out or 'continuously' if use is made of a strip-chart recorder.

(d) Air moisture content, air temperature and air flow conditions can be monitored continuously using a dew-point or relative humidity sensor, a temperature sensor, and a high flow-rate sensor, respectively, in conjunction with their respective meters and a strip-chart recorder.

Auxiliary Equipment

Some auxiliary instrumentation and equipment are necessary in addition to that recommended above for proper operation of the test facility. Thus, a controllable exhaust fan installation with control, release and bleed valves, and air flow metering instrumentation would be required. The exhaust fan is required to exhaust the radioactive mixture from the test facility into the atmosphere after adequate filtering to remove the decay products from the reference atmosphere in order to minimize environmental radiation hazards. Long-term stability suction pumps would also be necessary to recirculate daughter products into the test facility if so desired. Furthermore, differential pressure sensors should be installed in the test facility to ensure operation at negative pressure to minimize the possibility of accidental radioactive contamination of the personnel working area.

Radioactive Sources and Aerosol Sources

As indicated above, radon and thoron sources of the flow-through type are needed to produce the reference atmospheres. One or more sources of a

given kind, either in parallel or in series, might be necessary in order to attain the desired Working Level and daughter products concentration. Because of practical constraints and ease of handling, dry sources, e.g., inorganic salts of Ra-226 and Th-228, are recommended as sources of radon gas and thoron gas, respectively.

No primary or secondary standard sources of radon and thoron are required to produce the reference atmosphere as the latter can be determined accurately by standard methods and standard instrumentation, see below. However, it is important that the output of the source, i.e., radioactive gas concentration in Bq/L, as a function of air flow passing through the source be accurately known and traceable to, say, NBS standards. There are commercially available sources in Canada (e.g., Pylon in Ottawa) particularly suitable in the context of this discussion.

The airborne particulate composition and size distribution under typical field conditions such as an underground uranium mine where some mining activity is carried out is quite complex. In a typical situation, atmospheric aerosols, diesel particulates, smokes, oil and water mists and silica dust may be present in variable amounts. Hence, although it is recognized that the airborne particulate composition and size distribution in a test facility, such as the one described here, should approach field conditions as much as possible, it is also recognized that this might be quite difficult to accomplish, and in most cases of practical interest, not strictly necessary. It is, therefore, recommended that aerosol and aerosol sources of well known characteristics, and whose AMAD is within the required values be used in conjunction with the test facility.

There are a variety of aerosols suitable for use in the test facility. These include smokes, kerosene, DOP, latex, polystyrene, Ni-Cr, NaCl, and several

dyes such as Aniline blue, Methylene blue, and Fluorescein sodium (uranine). However, some of these aerosols are either flammable, corrosive, impractical to use or difficult to remove when adhered to walls. They may also have undesirable effects on instrumentation. Because of these and other practical reasons, it is suggested that aqueous solutions of NaCl be used, at least initially, in the configuration indicated previously. NaCl is an excellent, reproducible source of polydisperse aerosols whose AMAD is within the specifications suggested above and whose airborne concentration and size distribution can be varied easily according to practical needs.

If aerosols other than NaCl are used, it is advisable to adequately protect the internal walls of the test facility with easy-to-remove covering materials which can be replaced when necessary.

C. REFERENCE METHODS FOR DETERMINING RADON, THORON AND THEIR DAUGHTER PRODUCTS IN A REFERENCE ATMOSPHERE

There are a number of methods and analytical techniques presently available for determining the radiation level of radon daughter atmospheres. These methods include α-spectroscopy techniques, α/β counting, α-counting only and β-counting only methods (the latter including one, two or three total gross α-counts) and time-integrating techniques. Tsivoglou, Kusnetz, Thomas, Rolle, Hill, Markov, Keefe, Groer, James, Strong, Cliff, Schreve, among others must be credited with the development of some of the above methods. All these methods permit the determination of the Working Level. Some of the above methods also enable the determination of the radon daughter concentrations in addition to the Working Level. Any method carries an error associated with it which depends on the method itself. Spectroscopy methods are intrinsically more accurate than non-spectroscopy methods although the former are more complex and require more sophisticated instrumentation.

The use of α-spectroscopy methods for radon daughters is only recommended for very precise work in special applications. For more common, routine, applications the use of a modified form of the Tsivoglou method, and commonly known as the Thomas-Tsivoglou method, is recommended. This method enables the determination of the radon daughter concentration in addition to the radon daughter Working Level, WL(Rn).

A modified version of the Kusnetz method also consisting of one gross α-count but with different 'waiting' time and analytical procedure is recommended for the determination of the thoron daughter Working Level WL(Tn). (Note: if the concentration of ThB and ThC is also required in addition to WL(Tn), a two gross α-count can be used.)

For radon daughter/thoron daughter reference atmospheres the use of α-spectroscopy methods is recommended. All the methods indicated above for radon daughter, thoron daughter and mixtures of both are well known and will not be discussed here. A list of references is given at the end of this report for completeness.

The philosophy behind using only a given method for one particular application or group of applications is that errors due to the use of different methods are automatically eliminated. However, the members of the working group are aware that methods other than the ones recommended above can be used with comparable or marginally less error.

Although measurement of the radon and thoron gas concentration in the test facility is not a requirement for calibrating radiation instruments, it is useful in some cases. The techniques and methods used for this purpose have been briefly indicated in a different section.

D. REFERENCE RADIATION INSTRUMENTATION

Once a reference atmosphere has been defined and a reference method to measure this atmosphere has been chosen, it is most important to establish the requirements and characteristics that should be met by the instrumentation to be used to determine the reference atmosphere.

Basically, the instrumentation required should consist of a filter holder of the open face type capable of holding a 25 mm diameter filter, a filter suitable for radon and thoron daughter products sampling, a highly reliable servo-controlled, constant flow rate, sampling pump, and a long-term stability detector/scaler assembly. For simplicity, the filter/filter holder assembly and the detector/scaler assembly may be referred to as the sampling head and scaler, respectively. Also for simplicity, the entire system consisting of the sampling head, sampling pump and scaler will be referred to as the sampling/counting train.

An open face filter holder is necessary to minimize daughter products plate-out in the sampling head. A well designed filter holder will exhibit negligible plate-out.

There are several types of filters which are in principle suitable for sampling radon and thoron daughter products. Glass fibre, Nuclepore, Millipore and Fluoropore filters are suitable for sampling. However, the use of glass fibre filters is not recommended because of their high α-particle absorption. Nuclepore filters accumulate electrical charge relatively easily and are sometimes cumbersome and difficult to handle. Fluoropore filters are hydrophobic, and of excellent quality. The use of 0.8 μm AA type Millipore filters, is, however, recommended as the 'standard' filter. Filter self-absorption, although small, should be taken into consideration in all cases to apply pertinent corrections to the results.

The sampling pump should deliver a constant flow rate of at least 4-6 L/min and should be provided with a calibrated flowmeter to monitor the flow rate during sampling. It is recommended that the sampling pump has servo-controlled capabilities to ensure high degree of flow rate constancy over short and extended periods of time.

It is recommended that two independent sampling/counting trains be acquired and regularly cross-checked. Furthermore, it is recommended that the precision of the reference atmosphere measured with the reference instrumentation using the reference method(s) indicated above should be ± 5% or better.

E. OPERATIONAL PROCEDURES FOR THE CALIBRATION OF RADIATION INSTRUMENTS IN THE TEST FACILITY

As previously indicated, instrumentation used in radon and thoron daughter measurements consists basically of a sampling head, a sampling pump and a scaler. But while in many instances the sampling head and sampling pump are an integral unit physically independent from the scaler, some sophisticated instrumentation integrates all of the above elements into a single unit or system.

Calibration of instrumentation for radon and thoron daughter measurements can be divided into three main sections, relatively independent from one another, as follows:

1. Determination of the α-counting efficiency, ε, of the scaler;
2. Flow-rate, Q, calibration of the sampling pump; and
3. Overall calibration of the instrument in the reference atmosphere.

Although accurate knowledge of the α-counting efficiency of the scaler and the flow rate of the sampling pump is important for obvious reasons, it is not sufficient for accurate calibration purposes for the following reasons:

(a) The size and shape of the instrument greatly affects the air flow pattern around the instrument thereby influencing its daughter products collection efficiency. This effect depends not only upon the instrument size and shape, but on its sampling flow rate and the air flow characteristics of the radioactive atmosphere;

(b) The mechanical configuration of the instrument sampling head and its sampling flow rate play a very important role because they determine the plate-out (of daughter products) characteristics of the sampling head. For instance, under low aerosol concentration, the sampling heads of some instruments have been observed to plate-out up to 30 to 50% of the airborne decay products.

Because of the wide variety of sampling head mechanical configurations, sampling head flow rates (e.g., typically from 0.05 L/min to 30 L/min, approximately) and size and shape of radiation instruments, items (a) and (b) play an important role in the overall performance of the instrument. Consequently, it is of utmost importance to test instrumentation in reference atmospheres of known characteristics.

As previously indicated, measurement of the reference atmosphere should be carried out using the standard instrumentation described and the standard method suggested. Parallel measurements should be conducted with the reference instrument and the instrument under test. If the instrument under test can use any method, then comparison between the reference instrument and tested instrument should be made using the same method, e.g., Thomas-Tsivoglou. If the instrument being tested uses a method different from the reference method then comparison should be made between the reference method and the method used by the instrument under test. In any case, three samples of the reference atmosphere should be taken with each instrument and the mean value should be

used for calibration purposes.

Overall calibration of radiation instrumentation should be carried out twice a year. Additional calibration will be necessary if damage to the instrument occurs or is suspected.

The α-counting efficiency and sampling flow rate of the reference instrumentation should be determined, i.e., calibrated, on a monthly basis.

It is recommended that dry secondary Ra-226, Am-241 and Th-230 standard sources mounted on metal discs be used for α-counting efficiency calibration.

Calibrated bubble burettes and calibrated flowmeters are recommended for flow rate calibration. A set of bubble burettes and flowmeters covering the flow rate of interest (i.e., 0.05 L/min to 30 L/min, approximately) is recommended. Frequent cross-checking of the bubble burettes and flowmeter against a primary standard such as a spirometer or a primary standard bubble burette is advised. Cross-checking and/or interlaboratory comparison should be made twice a year. For less precise measurements a Wet Test Gas Meter (WTGM) could be used, although the performance of the instrument is considered somewhat variable. (Note: the flow rate range indicated above is necessary because flow rate calibrations are to be carried out on both reference radiation instrumentation and test radiation instrumentation, including low flow rate devices such as personal α-dosimeters.)

F. PRIMARY AND SECONDARY STANDARD SOURCES FOR THE DETERMINATION OF α-COUNTING EFFICIENCY

The α-counting efficiency of α-detectors and associated electronic circuitry, e.g., scaler, used in radiation instrumentation needs to be accurately determined because the overall calibration of the instrument depends on it. There are a variety of α-particle detectors in use including Si-barrier detectors,

diffused-junction (DJ) detectors, ZnS(Ag) screens, thermoluminescent detectors (TLD) such as LiF and CaF_2(Dy), and track-etch plastic detectors such as cellulose nitrate and CR39. Because the response of these detectors and associated electronic circuitry may not remain constant with α-particle energy and/or α-particle count rate, the need arises for determining the α-counting efficiency of these detector systems at different α-particle energies and α-particle count/rates. Hence, the need exists for a set of reference primary and secondary radioactive standard sources covering the energy and count/rate of interest.

PRIMARY STANDARD SOURCES

It is recognized that although some radioactive sources such as Am-241 are relatively easy to obtain or prepare, they are not the most appropriate ones for determining the α-counting efficiency of radiation instrumentation used in radon (thoron) daughter measurements where the average α-particle energy is close to 7 MeV, i.e., a significantly higher energy than that of 5.5 MeV corresponding to Am-241.

In order to cover the α-particle energy of interest, the following radioactive sources are recommended for α-counting efficiency calibration:

Th-230	E_α = 4.67 MeV	$T_{1/2} = 8\times10^4$ years
Am-241	E_α = 5.48 MeV	$T_{1/2}$ = 458 years
Ra-226	E_α = 4.77 MeV	$T_{1/2} = 1.62\times10^3$ years
(in equilibrium with	5.49 MeV	
its daughter products)	6.00 MeV	
	7.69 MeV	

where, in the above table E_α and $T_{1/2}$ stand for average α-particle energy and radioactive half-life, respectively.

Standard radioactive sources can be obtained in liquid form, i.e., as liquid solutions, and in solid form, i.e., as dry sources on metal discs. Because of the design and mechanical configuration of radiation instruments, in addition to a number of other practical and technical considerations, the use of liquid solutionsis ruled out.

Based on the above discussion, it is recommended that dry Am-241, Th-230 and Ra-226 sources deposited uniformly on metal discs be acquired and used as primary standard sources. As such these sources should be manufactured and calibrated by a leading world-wide reputed manufacturer, such as Amersham, and traceable to, say, NBS standards.

Because some radiation instruments admit sampling filters of a specific diameter only and because some radiation instrument users have particular preference for certain filter diameters, there is a need for obtaining standard radioactive sources of different diameters. Filter diameters of 25 mm, 37 mm and 47 mm are commonly employed although 25 mm filters are by far the most widely used. Thus, because only limited use of 37 mm and 47 mm diameter filters is made, correspondingly fewer standard sources of a given radioisotope with these diameters are required.

An important consideration in the preparation of the primary standard sources is that of uniformity of the radioisotope on the metal disc.

In order to simulate as closely as possible the deposition of radionuclides on sampling filters under normal air sampling conditions, it is recommended that the radioactive standard sources be deposited uniformly on metal discs of the same diameter as the diameter of the filters in common use, i.e., 25 mm, 37 mm and 47 mm. However, the 'active' diameter of the source should be slightly less (about 2 to 4 mm, to be specified at the moment of purchasing) than the corresponding disc.

The radioactive strength of the primary standard sources should cover a range corresponding to the WL range most likely to be encountered under field conditions with a confidence margin to deal with unusual situations. It is therefore recommended that the radioactive source strength should cover the range from 0.02 WL (corresponding to the maximum recommended by AECB for residential areas, i.e., housing) to 100 WL, a radiation level which might arise in an unventilated high grade ore uranium mine site where no mining activity has been carried out for some time. It is particularly important to calibrate instruments with source strengths corresponding to 0.3 WL, i.e., the recommended maximum exposure level for occupational workers in the uranium mining industry.

The radioactive source strength of the primary standard can be determined from the following expression:

$$S = T_s \cdot Q \cdot K \cdot WL = V \cdot K \cdot WL \qquad \text{Eq 1}$$

where in the above Equation:

T_s is the sampling time (min);

Q is the sampling flow rate (L/min);

K is a conversion factor (K = 100 in our case);

S is the source strength in disintegrations per min (dpm).

Note: that if the α-counting efficiency of the detector/scaler system is denoted by ε and the α-count rate of the instrument, in counts per min, is denoted by cpm then dpm = cpm/ε. Furthermore, $V = T_sQ$ represents the total volume of air sampled.

Taking V = 30 L and K = 100, Equation 1 gives:

$$S = 3 \times 10^3 \text{ WL (dpm)} \qquad \text{Eq 2}$$

It is recommended that the following WLs be chosen for the calculation of S: 0.02, 0.3, 1.0, 5.0, 10, 50 and 100. The values obtained are given in the Table below. The values in round brackets are rounded off values.

Table 1 - Source strength corresponding to a given Working Level

WL	S (dpm)
0.02	60 (10^2)
0.30	900 (10^3)
1.00	3×10^3
5.00	1.5×10^4
10.00	3.0×10^4
50.00	1.5×10^5
100.00	3.0×10^5

It is recommended that 25 mm primary standard sources of Am-241, Th-230 and Ra-226 be procured. The strength of the sources corresponding to each radioisotope should cover the range indicated above in steps as shown in Table 1. Hence a total of 3 x 7 = 21 primary standard sources of 25 mm diameter are required.

Primary standard sources of 37 mm and 47 mm diameter are also required. However, in this case only one source strength of 10^4 dpm is considered necessary. Hence three 37 mm and three 47 mm primary standard sources of the above radioisotopes are needed. The total number of primary standard sources recommended is, therefore, 21 + 3 + 3 = 27.

The primary standard sources are to be used only on very rare occasions, mainly for calibrating secondary standard sources to be used in routine α-counting efficiency determination of radiation instruments. The primary standard sources should be kept at all times in specially designed protective containers, in sets of radioisotopes of the same kind. The containers are to be kept in a safe where only two people will know the combination for security reasons.

SECONDARY STANDARD SOURCES

As previously indicated, the use of primary standard sources for routine α-counting efficiency measurements would be both impractical and not advisable. It is, therefore, recommended that twin sets of radioactive sources of the same kind as those described above be prepared, say, in-house, and accurately calibrated against the primary standards. They could also be purchased commercially or obtained from the MOL, for example. These sources will be referred to as secondary standard sources.

The main application of secondary standard sources would be for routine work, and to calibrate other sources, i.e., tertiary standard sources, which could be used by the uranium mining industry for checking their instruments and for less precise calibration work.

Secondary standard sources should be recalibrated periodically against the primary standard sources at least twice a year, or more often should the need arise.

The α-counting efficiency of the reference instrumentation and other radiation instrumentation should be determined, respectively, on a monthly basis and twice a year, or more often if damage to the instrument is suspected or confirmed, using the secondary standard sources. Furthermore, measurements should be carried out with at least three different source strengths for each radioisotope. It is recommended that source strengths corresponding to 0.02 WL ($\sim 10^2$ cpm), 0.3 WL ($\sim 10^3$ cpm) and 3 WL ($\sim 10^4$ cpm) be used to check for an instrument's linearity. In cases where the instrument is to be used under high WL field conditions, correspondingly high source strengths should be used. An average or mean value of the results should be used.

C. PRIMARY AND SECONDARY STANDARD SOURCES FOR RADON AND THORON

Even though knowledge of radon (thoron) gas concentration in a test facility is not indispensable, it is nevertheless important as, in conjunction with WL measurements, it enables the determination of the gas concentration to Working Level ratio, a relevant variable in underground uranium mines. Furthermore, knowledge of the above ratio enables replication of radioactive reference atmospheres with the characteristics of field conditions. Hence, precise determination of radon (thoron) gas concentrations is relevant in the context of the test facility.

There are a number of methods suitable for determining, say, radon gas concentrations (see references). However, scintillation cells, of different sizes and shapes coated with ZnS(Ag), optically coupled to a photomultiplier tube (PMT), in conjunction with a suitable scaler, represents the most widely used method. The radon detector and associated electronic and measuring circuitry require careful calibration by means of radon gas standard sources.

RADON GAS PRIMARY STANDARD

It is recommended that a standard Ra-226 solution using the standard bubble de-emanation method be used as a radon gas primary standard source. The method is well documented in the literature.

A number of scintillation cells of a given size and shape should be built and calibrated with the primary standard. The cells are to be calibrated in conjunction with a 'dedicated' PMT/scaler system. These cells will be referred to as the standard scintillation cells. They should be calibrated twice a year and should only be used in the laboratory for precise measurements. Inter-comparison measurements with other laboratories with similar standard sources are strongly recommended. It is further recommended that a total

of two 'dedicated ' PMT/scaler systems be available, one of the systems as a back-up. In addition, one or two scintillation cells should be built with a Ra-226 'dry' source inside in order to check the PMT/scaler counting efficiency periodically.

RADON GAS SECONDARY STANDARDS

It is suggested that a radon gas secondary standard of the static type traceable to NBS standards, such as that commercially available from Pylon (Model RN-1015), be available for routine, less precise, work. In addition, a number of scintillation cells should be built for field work and laboratory work. These cells should be calibrated against the secondary standard periodically as needed, e.g., every three months. For simplicity, these cells will be referred to as secondary scintillation cells. They should be calibrated in conjunction with the PMT/scaler systems indicated above.

Radon gas sources of the flow-through type similar to those previously described for use in the test facility would be necessary to investigate dynamic behaviour and plate-out phenomena in scintillation cells and to test radiation instrumentation sampling heads.

The same considerations discussed above for radon sources apply equally well to the case of thoron sources.

H. LONG-LIVED RADIOACTIVE DUST - URANIUM AND THORIUM STANDARD SOURCES

In addition to the short-lived decay products of radon and thoron, long-lived airborne α-particle emitters such as uranium (U-238) and thorium (Th-232), the two parents of the two naturally occurring uranium and thorium radioactive decay chains, and their long-lived decay products contribute to the radiation exposure of occupational workers in uranium mines, mills, and refining and processing plants. U-238, Th-232, and their long-lived decay

products are mainly associated with dust in the respirable size range, and coarser dust, forming what is commonly referred to as the long-lived radioactive dust. (Note: because of the presence of U-238 and Th-232 in long-lived radioactive dust, the dust also contains short-lived decay products of Ra-226 and Ra-224 formed, respectively, from the decay of the above parents. An exception to this is when Ra-226 and thorium compounds are removed in the milling and/or refining process.)

Because of the presence of long-lived radioactive dust in certain uranium industry operations, the need arises for determining its concentration in air and hence (a) for developing adequate methods and techniques for its measurement, and (b) for acquiring standard radioactive sources for activity comparison purposes.

The usual procedure for determining uranium and thorium in long-lived dust or airborne dust, in general, is as follows:

(a) Air sampling with a high flow-rate pump and adequate filter over a relatively long period of time to secure enough sample for analysis;

(b) Chemical or physical processing of the sample including separation, if necessary, and analysis by chemical means; or

(c) Comparison of sample solution with standard uranium and thorium standard solutions by some physical method or technique, e.g., fluorometry or colorimetry.

The procedures suggested for the determination of thorium and uranium are those followed by the AECB laboratory given below.

OUTLINE OF THORIUM PROCEDURE

The method is essentially that described by G.L. Smithson in "Radio chemical Procedures for Determination of Selected Members of the Uranium and Thorium Series", CANMET Report 78-82. The sample is brought into solution and thorium is isolated by co-precipitation first with lanthanum hydroxide, then

with lanthanum fluoride, followed by extraction with thenoyltrifluoroacetone (TTA) in a suitable solvent. The organic extract is stripped with a nitric acid solution to produce an aqueous solution of thorium nitrate. The nitrate is removed by evaporation with H_2SO_4 or $HClO_4$, and the colour development is performed by reacting a strong HCL solution (approximately 6M) of the isolated thorium with an aqueous solution of Arsenazo III. The colorimetric measurement is then performed at a wavelength of 665 nm.

OUTLINE OF URANIUM PROCEDURE

The method is essentially that described by J.C. Robbins and C. Castledi in "Analytical Procedures for UA-3 Uranium Analysis", Application Brief 79-1, March 1979, issued by Scintrex, 222 Snidercroft Rd., Concord, Ontario. The filters (preferably Gelman GN-6 or DM-450) and the collected sample of aerosol are dissolved by digestion with 15 M HNO_3. (If any residue occurs it is brought into solution by Na_2CO_3 fusion and digestion of the cake with HNO_3.) The sample is diluted to 25 mL and an aliquot is transferred to the measurement cell. Addition of "Fluran" (a buffered inorganic phosphate solution) produces a uranyl phosphate complex which fluoresces upon excitation by a pulsed beam from a nitrogen laser. The intensity of the fluorescence is measured and the U concentration determined by a 'standard addition' technique.

Uranium and thorium solution standards of different concentrations are available from NBS. It is recommended that a set of both radioisotopes covering a wide range of concentrations be used to determine long-lived radioactive dust concentrations.

I. BETA RADIATION

Not much work has been done regarding the contribution from β-radiation to the total occupational exposure arising from the inhalation of short-lived decay products of radon and thoron (e.g., RaB, RaC, ThB) and long-lived

radioactive dust (e.g., Ac-228, Ra-228 and other β-emitters). The case for H-3, C-14 and I-131 at reactor sites may, perhaps, be better documented.

Although the contribution to the total dose or tissue damage caused by inhalation of β-particle emitters may be argued to be much less than that corresponding to α-radiation for the radioisotopes of interest, it might, nevertheless, be significant enough to take it into consideration in the future. At present, however, there are no regulatory limits of exposure to airborne β-emitters by the AECB for most uranium-related industries.

J. OTHER TOPICS AND CONCLUSIONS

The subject of radon and thoron and their short-lived decay products has been treated in adequate detail for the purpose of the establishment of practical reference standards for calibration purposes in Canada. However, other important topics, including long-lived radioactive dust and β-radiation have not been dealt with in sufficient detail. This has been partly due to the fact that less information is presently available on these topics and partly, but most importantly, because of the absence of experts in the field of nuclear reactors, and uranium mills, refining and processing plants, at the scheduled meetings of the Working Group on Airborne Radioactive Contaminants.

In spite of the above shortcomings and difficulties, it is the consensus, opinion and suggestion of the members of the Working Group who attended the regular meetings that the same considerations and recommendations made for the case of radon, thoron and their short-lived decay products in the uranium mining industry should, in general, also apply to other uranium-related industries (i.e., mills, refining and processing plants and reactor sites) suitably modified, however, to deal with the particular radioisotopes of interest. However, as airborne radioactive contaminants at reactor sites are

mainly determined for monitoring purposes, it has been suggested by some members of the Working Group that some of the recommendations made in this report should not apply to this particular case.

K. SUMMARY OF RECOMMENDATIONS

The main recommendations of the Working Group on Airborne Contaminants pertaining to the establishment of reference standards for radon, thoron and their decay products are given below. The recommendations have been summarized from the work presented in this report, and are as follows:

1. To design and build a calibration facility, i.e., chamber, for producing reference atmospheres of radon daughters, thoron daughters or a mixture of both, for calibration purposes. The chamber should have a volume between 1×10^4 L and 3×10^4 L and be fully equipped with radon, thoron and aerosol generating capabilities in addition to having facilities to change relative humidity, temperature, ion content and air flow. Furthermore, the chamber should have monitoring capabilities for radon and thoron, and their daughter products, aerosol concentration and size distribution, and meteorological variables;
2. The calibration facility should be capable of reproducing easily two standard radon daughter and thoron daughter reference atmospheres of the following characteristics:

'Normal' Reference Atmosphere

Working Level (WL):	0.1 to 3.0	(0.3)
Disequilibrium ratio:	~1:0.6:0.4	(for radon daughters)
Disequilibrium ratio:	~[ThC]/[ThB] ≈0.5	(for thoron daughters)
Aerosol concentration (N):	$\geq 10^3$ cm^{-3}	

Average Median Aerodynamic Diameter (AMAD):	0.1 to 0.2 μm	(polydispersed)
Relative Humidity (R.H.)	50% to 80%	(70%)
Temperature (T):	20 ± 3°C	

'Extreme' Reference Atmosphere

Working Level (WL):	0.1 to 3.0	(0.3)
Disequilibrium ratio:	~1:0.6:0.4	(for radon daughters)
Disequilibrium ratio:	~[ThC]/[ThB] ≈0.5	(for thoron daughters)
Aerosol concentration (N):	$\gtrsim 10^3$ cm^{-3}	
AMAD:	0.1 to 0.2 μm	
Relative humidity (R.H.):	10% to 50%	(30%)
Temperature (T):	20 ± 3°C	

3. It is suggested that the Thomas-Tsivoglou method, a modified form of the Kusnetz method, and an α-spectroscopy method be adopted for the determination of radon daughters, thoron daughters, and a mixture of both, respectively;
4. The determination of radiation levels in the calibration facility is to be conducted by means of reference instrumentation consisting of the following items: an open-face filter holder with a Millipore 0.8 μm AA type filter, a 4-6 L/min flow rate servo-controlled sampling pump with calibrated flowmeter, and a ZnS(Ag)-screen α-scaler. Two such systems are required for cross-checking and as a back-up. The precision of the reference atmosphere measured with the reference instrumentation using the reference method(s) indicated in item 3 should be ± 5% or better;
5. Calibration of radiation instrumentation used for routine monitoring of radon and thoron daughters in uranium mines and other related industries should be divided into: (a) flow rate calibration of the sampling pump; (b) determination of the α-counting efficiency of the detector/scaler

assembly; and (c) overall calibration of the instrument in the reference atmosphere;

6. Radiation instrumentation should be calibrated twice a year (see item 5). Cross-checking of the reference instrumentation with standard radioactive reference sources (see below) and calibrated flowmeters and burettes should be carried out on a monthly basis. Frequent intercomparison with other laboratories is strongly advised;

7. The calibration facility should be provided with calibrated flowmeters and burettes for accurate calibration of sampling pumps, and primary and secondary standard (reference) sources for the determination of α-counting efficiency, ε, of detector/scaler assemblies. Traceability to, say NBS standards, is in all cases imperative;

8. A set of primary standard (reference) sources of Am-241, Th-230 and Ra-226 covering the source strength range from 1×10^2 dpm to 3×10^5 dpm, and of several diameters (25 mm, 37 mm and 47 mm) are required (a) to calibrate secondary standard (reference) sources of the same type, and (b) to determine ε as a function of α-energy. A total of 27 sources are recommended. The sources should be of the dry type and mounted on metal discs. Primary standards are to be kept at all times in specially designed protective containers in sets of radioisotopes of the same kind. The containers are to be kept in a safe where only two people should know the combination for security reasons. Similar precautions should be adopted for secondary standards of the above or other kind;

9. A set of secondary standard (reference) sources should be acquired and calibrated against the primary standards. The secondary reference sources are the ones to be used in routine determination of ε. These sources

should be rechecked twice a year and should also be intercompared periodically with other laboratories;

10. A Ra-226 standard solution is recommended as a primary source of Rn-222 by using the bubble de-emanation method. A set of scintillation cells are to be built and calibrated with the primary standard to be used for delicate work, i.e., reference scintillation cells. It is also suggested that a second set of scintillation cells be built and calibrated against the reference cells for less precise and routine work. Reference scintillation cells should be calibrated twice a year. Two 'dedicated' scalers are to be used in conjunction with the scintillation cells. In addition, two scintillation cells should be built with a Ra-226 'dry' source inside, in order to check the scaler α-counting efficiency periodically.

11. It is suggested that a radon gas secondary standard of the static type traceable to NBS standards, such as that commercially available from Pylon (Model RN-1015), be available for routine, less precise work. Also radon gas sources of the flow-through type similar to those previously described for use in the test facility would be necessary to investigate dynamic behaviour and plate-out phenomena in scintillation cells and to test radiation instrumentation sampling heads. The same considerations discussed above for radon sources apply equally well to the case of thoron sources;

12. Instruments calibrated in the calibration facility will be issued a certificate of performance, the format of which is to be decided at a later date;

13. No decision has been made pertaining to calibration charges on a cost recovery basis;

14. Calibration should be conducted by a trained technologist (to be hired) supervised by the senior scientist in charge of the calibration facility;
15. The above recommendations apply to the uranium related industry whenever air sampling is conducted for dosimetric purposes to evaluate personal dose exposure. When sampling is carried out for monitoring purposes only, these recommendations do not apply (e.g., reactor sites).

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MONITORING INSTRUMENTS

No. in Use*	Type
39	H&H Custom Pump
1	Victoreen Panoramic Survey Meter 470A for αβγ Determination
26	Nurad Scintillometer
10	Constant Flow Sampler Pumps - Dupont P4000 Air Sampler
2	Nuclear Enterprises Pumps
1	Dupont Constant Flow Sampler Calibrator
3	Canada Aviation Electronics Scintillometers
16	Lucas Cells (Glass 02 Filter Paper)
3	MDA Scientific Instant Working Level Meter
1	Vacuum Pump - EDA
13	Tri-Met Instruments Scintillometer Counter
1	Dupont 2L Per Minute Sampler
2	Radon Survey Meter Victoreen αβγ
3	Bendix 2L Per Minute Samplers
14	MSA Model G Air Sampling Pumps (Uranium Dust)
1	Eberline RGM-2 Radon Gas Monitor (Continuous)
1	Ludlum Model 3 (Adapted for Alpha Counter) Geiger Counter
3	Eberline SPA1 Working Level Detector (Millipore Scintillation)
3	Eberline Model SAC-4 Scintillation Alpha Counter
1	Eberline PRS 1 SAC-5 Working Level Determination Portable Rate Meter Scaler
2	EDA RD200 Radon Detector (Detect Radon in Air & Water)
3	Sampling Heads for Super Sampler Pump (Bendix)
2	Bendix Env. Scien. Div. BD x 44 Super Sampler Air Sampling Pumps
3	GMW 2000 Dust Samplers
18+	Konimeters
1	GMW 2000A Dust Sampler
2	BDX-60 Area Dust Samplers (Bendix)
1	Eberline Alpha AC3-8 Probe
1	Eberline Alpha R014 PM Assembly
1	EDA Alpha Scintillation Counter RDA-200
1	CEA Alpha Scintillation Counter Marnac
1	Nardeux αβγ IPAB-70 Rate-meter with Probe
1	MDA Instant Working Level Meter IWLM 811
2	EDA Continuous WL Monitor WLM-300
1	CEA Continuous Radon Monitor
4	Eberline αβγ Hard Monitors HM-4
1	Eberline Alpha-5 Air Monitor
1	Nardeux Babyline 3-1 Ionization Chamber
>200	CEA Track-Etch Personal α-dosimeters
>50	Alpha-NUCLEAR Personal α-dosimeters

* Mainly in use by the uranium industry, government agencies and research institutions in the Provinces of Ontario and Saskatchewan.

POOR

QUALITY

ORIGINAL